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RIFLE RECOIL AND MUZZLE SHOCK EFFECTS UPON A WAR GAMES OPTICAL COMMUNICATIONS CONCEPT

by

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ABSTRACT. This report presents the results of experiments conducted to determine the origin, magnitude, and characteristics of signal interference in the Direct Fire Simulation System (DFSS) communications caused by weapon recoil and shock wave effects. The two effects were considered independently and were investigated using an M-1 (.30 caliber) and an M-16 (.233 caliber) rifle. Of primary concern in this investigation were the effects of blank ammunition although a limited amount of data was gathered on ball ammunition. Transmission time intervals required for sending and receiving a coded message, as related to various mechanical aspects of the rifles, were also investigated.

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA * OCTOBER 1969

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FOREWORD

The work described in this report was performed as part of the continuing research program of the Naval Weapons Center (NWC). The work was supported by the Instrument Support Group, U.S. Army Combat Developments Command, Fort Ord, Calif.

This report was reviewed for technical accuracy by H. P. Leet and L. W. Nichols.

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INTRODUCTION

The Direct Fire Simulation System (DFSS) concept[1] proposed a method of accounting for the number of rounds of ammunition expended versus hits obtained in a war games situation. The method proposed mounting a coded source of invisible radiation on a weapon to serve as a message transmitter and attaching highly sensitive, small-area detectors on personnel and various types of military vehicles for message reception. The coded message would convey the identity of the initiating source and, if detected, be relayed to a central decision computer along with the identity of the object that received the message. Firing a blank round of ammunition would key a weapon-mounted "round counter" that in turn would key message transmission. Detected "hits" would be stored in a local buffer memory until interrogated by the central computer through a data link. The computer would then make all hit/kill decisions and inform the object that received the message. However, as indicated by the name given to the system, only line-of-sight encounters are considered in the concept.

This report presents the results of experiments conducted at the Naval Weapons Center (NWC), China Lake, for the Instrumentation Support Group, U.S. Army Combat Developments Command, Fort Ord, Calif., to determine the magnitude of received signal interference caused by weapon recoil and shock wave effects. The two effects were considered independently and these were investigated using the M-1 (.30 caliber) and M-16 (.233 caliber) rifles. Although the primary concern in this investigation were the effects of blank ammunition, a limited amount of data was gathered on ball ammunition. A blank adapter was installed on the muzzle whenever blank ammunition was used.

The DFSS concept considers weapons that vary from small-bore rifles to large-caliber guns. Due to the size, weight, and power requirements and the need for visual security, solid-state light-emitting diodes or injection laser diodes provide the logical choice for a message transmitter. Such devices, as well as a continuous-wave (C-W) helium-neon (He:Ne) laser, were used as radiation sources during the NWC investigation.

[1]Stanford Research Institute. Direct Fire Simulation System, by Kenneth W. Gardiner and others. Menlo Park, SRI, Calif., October 1966. (SRI Project No. 5860; AD 648-069.)

SHOCK WAVE EFFECTS

To determine the effects of the muzzle shock wave upon the transmitted message, a mirror was positioned independently of the rifle to project the beam from a C-W He:Ne laser colinearly with the rifle bore so that the rifle discharge would occur within 2 inches of the beam. This method was used to remove the laser from the high acoustical overpressures occurring near the muzzle and to allow a realistic proximity of the beam to the muzzle, as dictated by the proposed concept. The beam was incident upon a gridded target 50 yards down range. As a round of ammunition was fired, the muzzle shock wave interfered with the He:Ne beam. The effect of this interference, and its duration, were recorded by photographing the target with a high-speed motion picture camera operating at 3,200 frames/second. The duration of any disturbance was obtained from timing lights mounted in the camera.

A pulsed gallium-arsenide (Ga:As) laser transmitter was also positioned so that its wavefront would travel in close proximity (1 to 2 inches) to the muzzle. A totally reflecting mirror was placed near the gridded target to intercept the beam and redirect it to a wide field-of-view silicon photodetector located behind and approximately 3 feet to the side of the rifle muzzle. This separation was chosen to approximate the geometry of a rifleman's weapon and his own detection set. Thus, muzzle blast effects on the transmitted message and on the detector could be determined. Signals received at the detector were amplified, displayed, and photographed on an oscilloscope. In early tests a crystal microphone was attached to the stock of the rifle to trigger the oscilloscope sweep upon reception of the noise created by the hammer hitting the firing pin of the weapon. In later tests a microswitch attached to the trigger served a similar purpose. The oscilloscope sweep was initiated 3 to 5 milliseconds before any disruption from the muzzle blast occurred. In later tests the pulsed Ga:As transmitter was replaced with a C-W Ga:As light-emitting diode transmitter.

He:Ne INVESTIGATIONS

Figures 1 and 2 are selected strips of the high-speed motion pictures taken during the firing of ball and blank ammunition for the M-1 and M-16 rifles, respectively. The first strip shows the undisturbed He:Ne beam before cartridge detonation. The succeeding series of frames shows the beam distortion at various times after cartridge detonation. General analysis of these figures reveals that while the position of the beam pattern on the target varies slightly with respect to the undisturbed position, the effects of absorption and scattering are quite severe. Ball ammunition produced greater periods of disruption than blank loads.

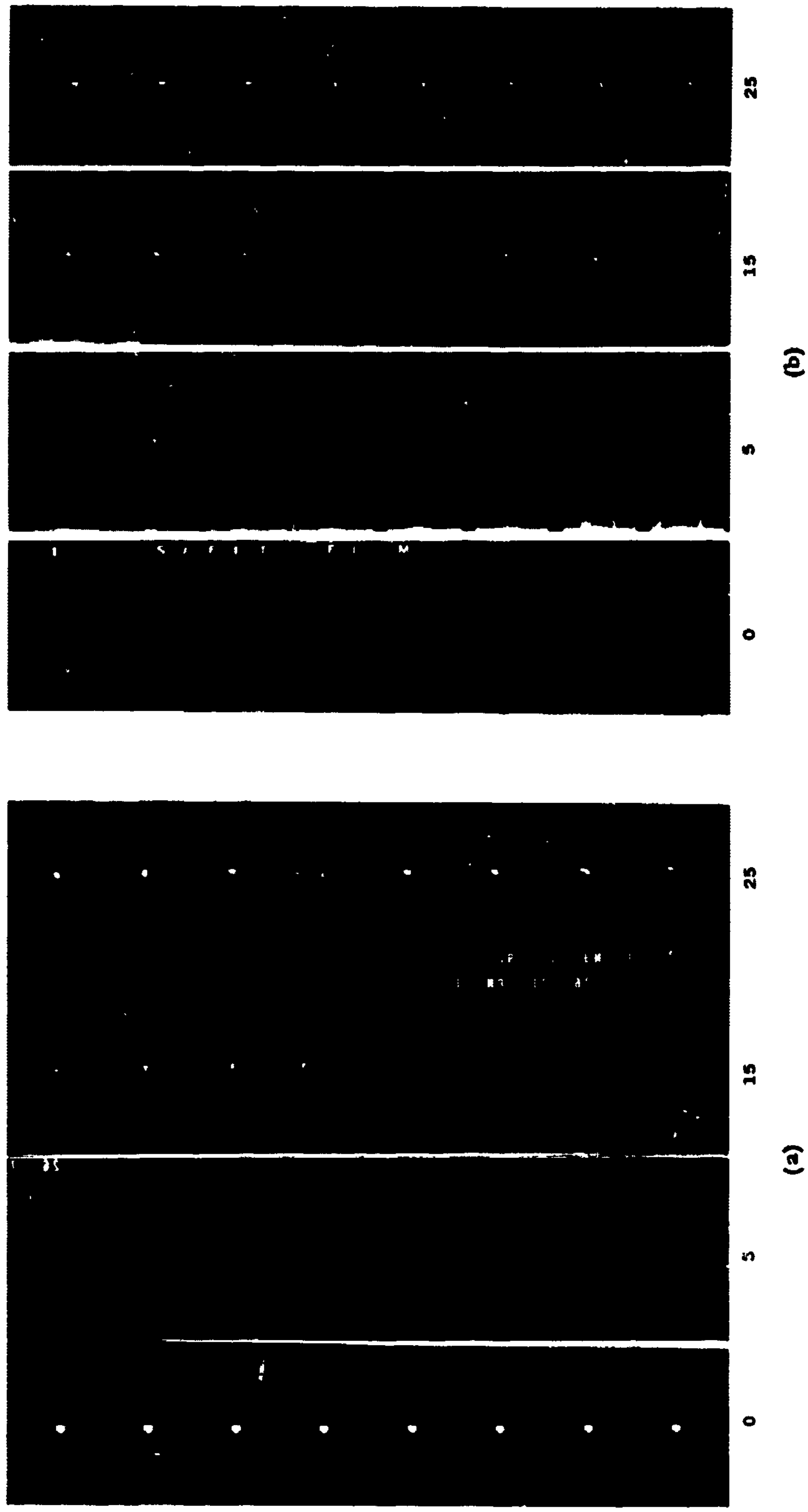


FIG. 1. Effects of (a) Ball and (b) Blank Ammunition on a Laser Wavefront Using an M-1 Rifle. The numbers define the time lapse (in milliseconds) after cartridge detonation. Frame rate: 3200 fps.

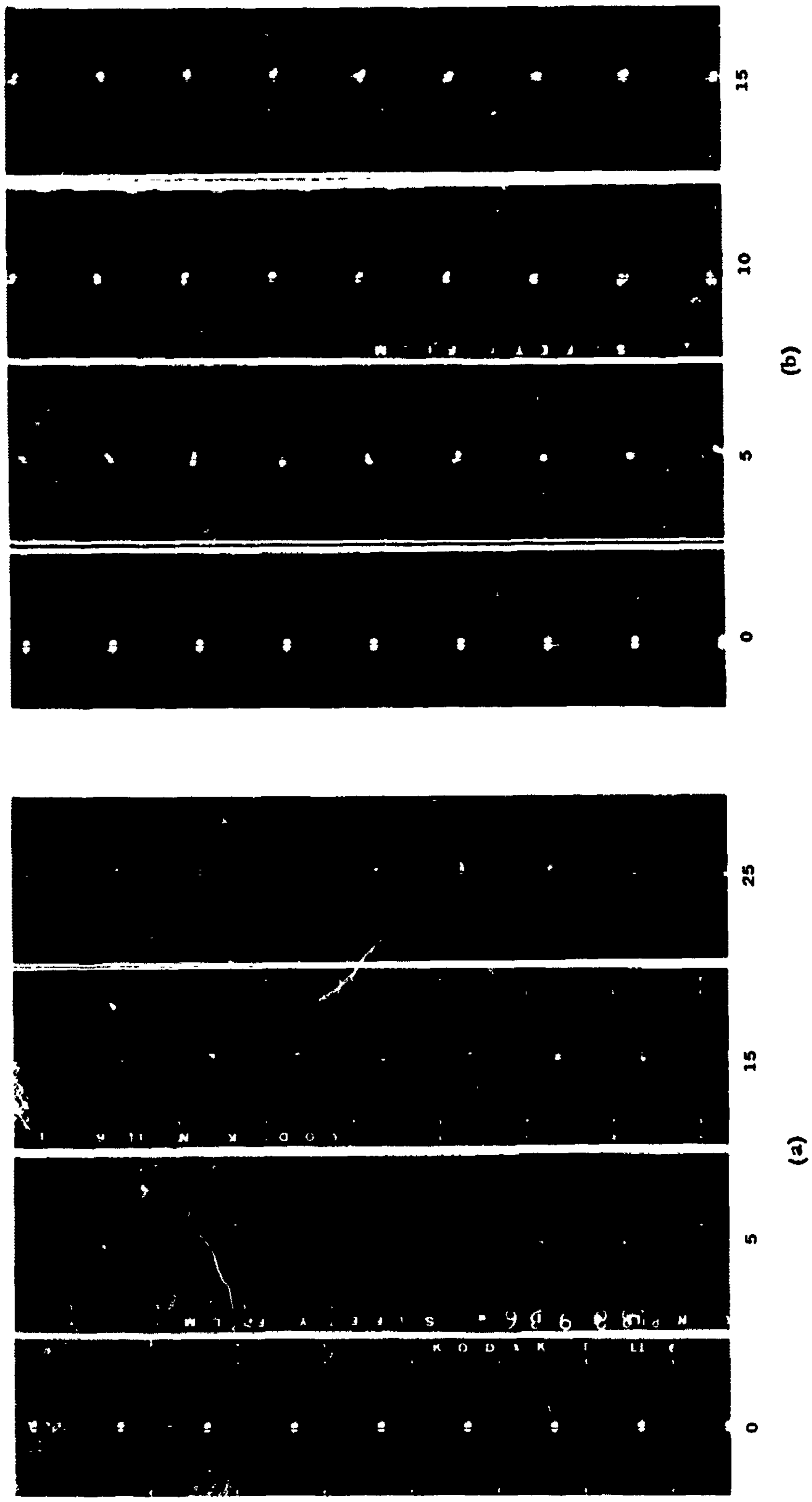


FIG. 2. Effects of (a) Ball and (b) Blank Ammunition on a Laser Wavefront Using an M-16 Rifle. The numbers define the time lapse (in milliseconds) after cartridge detonation. Frame rate: 3200 fps.

Table 1 compares the disruption periods caused by ball and blank ammunition fired in the M-1 and the M-16 rifles and lists the average time after cartridge detonation for the laser-beam pattern to return to a given percent of normal. "Normal" is defined as the position and pattern of the He:Ne beam on the target immediately before discharge. Thus, at 50% normal, approximately one-half of the original area covered by the beam would be effective for message transmission.

TABLE 1. Comparison of Signal Disruption Periods Due to Muzzle Blast Effects

Type of ammo	Beam disruption time					
	M-1 rifle			M-16 rifle		
	50% of normal, ms	75% of normal, ms	Return to normal, ms	50% of normal, ms	75% of normal, ms	Return to normal, ms
Ball	20	35	65	12	25	50
Blank	15	25	50	6	15	35

Ga:As INVESTIGATIONS

Deleterious effects were also revealed on the train of pulses received from the Ga:As transmitter. The signal train was emitted at a rate of 1,000 pulses/second and signal amplitude measured at the transmitter was constant to within ±5%. Figure 3 is a typical example of the data collected from the silicon detector.

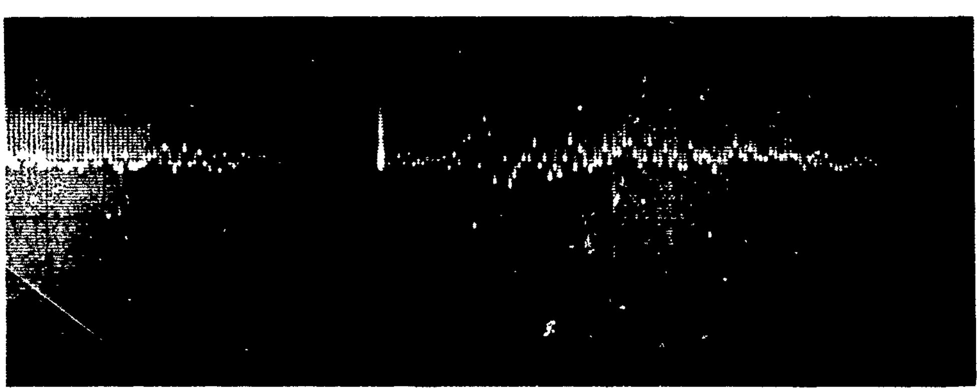


FIG. 3. Signals Received Before and During the Firing of One Round of .223 Caliber Blank Ammunition Using a Pulsed Ga:As Laser Transmitter. Horizontal scale, 5 ms/div.; vertical scale, 2 v/div.

In another series of tests a C-W Ga:As light-emitting diode transmitter, transmitting at 50 kilohertz, was substituted for the laser transmitter. Other test procedures remained constant. Figure 4 is a typical example of the data collected in this configuration.

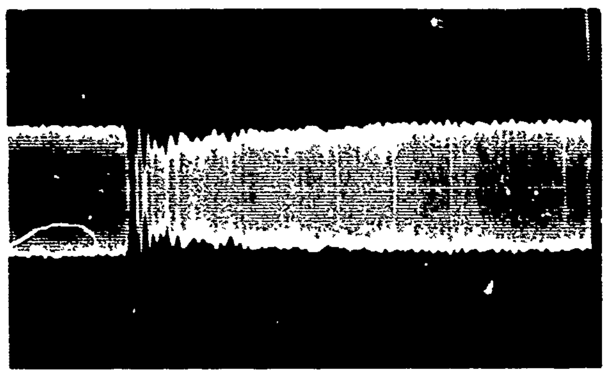


FIG. 4. Signals Received Before and During the Firing of One Round of .223 Caliber Blank Ammunition Using a C-W Ga:As Light-Emitting Diode. Horizontal scale, 5 ms/div.; vertical scale, 2 v/div.

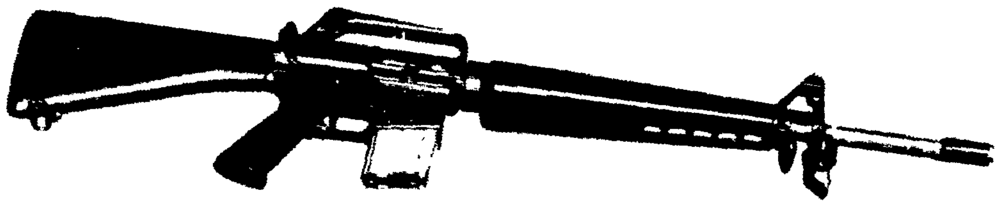
No serious effects of muzzle shock or afterburning were noticed on the silicon detector set. This was particularly true with blank ammunition. On the occasions when the detector responded to the afterburning radiation, the pulse was of such magnitude and duration that it could be accommodated or discriminated, thus avoiding the recording of erroneous data.

The foregoing tests indicated that the shock wave generated from firing a blank M-1 or M-16 round would not seriously impair the DFSS signals nor disrupt them in a manner that could not be accommodated. It should be re-emphasized that all of these tests were conducted with the transmitter mounted independently of the rifle.

RIFLE RECOIL

To determine the effect of rifle recoil on the DFSS signal transmission and reception, a small light-weight mirror was mounted on the bayonet stub of the weapons to project a He:Ne laser beam toward a gridded target (Fig. 5). High-speed motion pictures recorded the data.

(a)



(b)

FIG. 5. Diverting Mirror Attached to Bayonet Stub of the (a) M-1 and (b) M-16 Rifles.

A short focal length lens was selected for the camera to cover the 2- by 2-foot target at an appropriate range. As the rifle was discharged, the associated recoil caused the laser beam to trace a light path across the target. This motion was recorded by the camera and the film was then analyzed to determine the relative position of the beam on the target with respect to time. The magnitude and direction of the horizontal and vertical components of the rifle recoil, and its resultant motion, were determined. Figures 6 and 7 are plots of the angular displacement (horizontal and vertical components) of the laser beam as a result of weapon discharge from the M-1 rifle using blank ammunition. Figures 8 and 9 represent similar data for the M-16 rifle. The numbers appearing in the centers of the beam outlines represent the time (in milliseconds) when the beam occupied that position after weapon discharge. The distortion of the beam outline reveals the action of muzzle blast on the laser beam during the first critical moments after the weapon was discharged. These plots were repeatable in substance throughout the experiment.

Since the procedure for gathering this data involved the reflection of the He:Ne beam off of a mirror attached directly to the rifle, consideration was given to the angular relationships introduced by the moving mirror. Effect of translation was negligible because the beam always remained within the boundaries of the small mirror. Given a pivot point at the bayonet stub, there were three rotations possible: azimuth, elevation, and roll. Examination of the optical geometry revealed that the angular change in the reflected beam was twice the azimuth angle change of the weapon. In elevation, the relationship

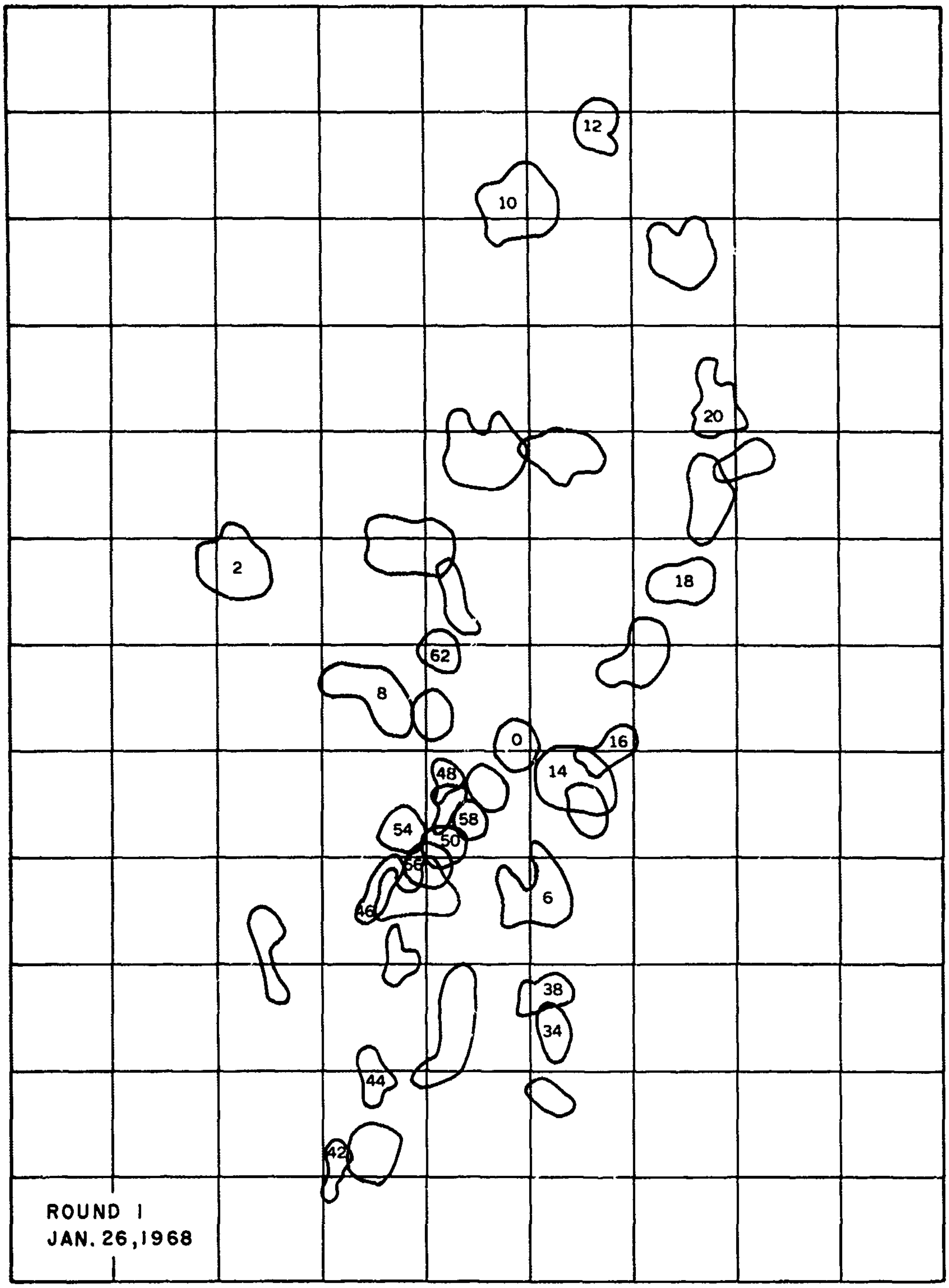


FIG. 6. Angular Displacement of the Discharge of the M-1 Rifle. Horizontal scale, 1.042 mrad/div; vertical scale, .521 mrad/div.

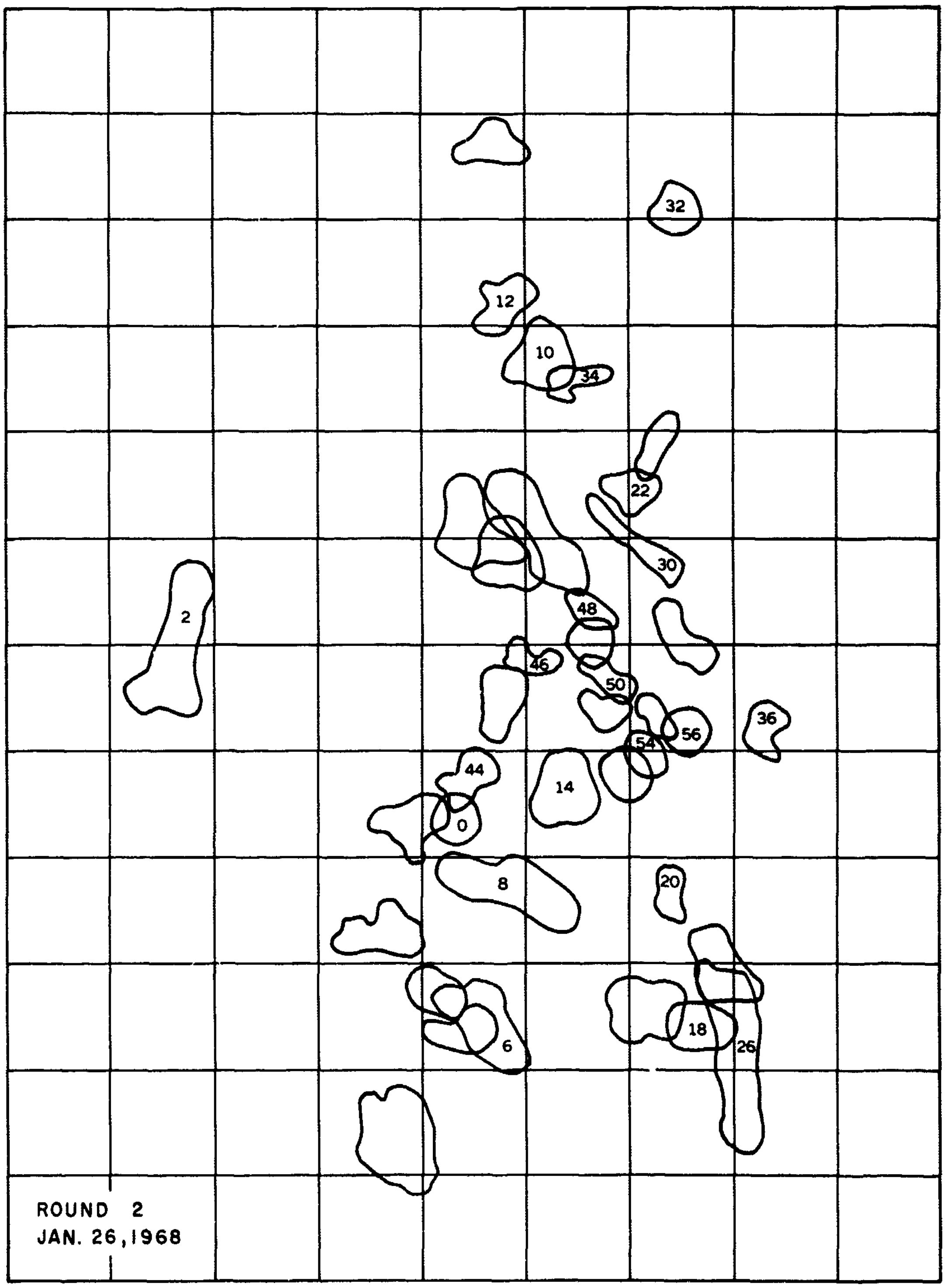


FIG. 7. Angular Displacement of the Discharge of the M-1 Rifle. Horizontal scale, 1.042 mrad/div; vertical scale, .521 mrad/div.

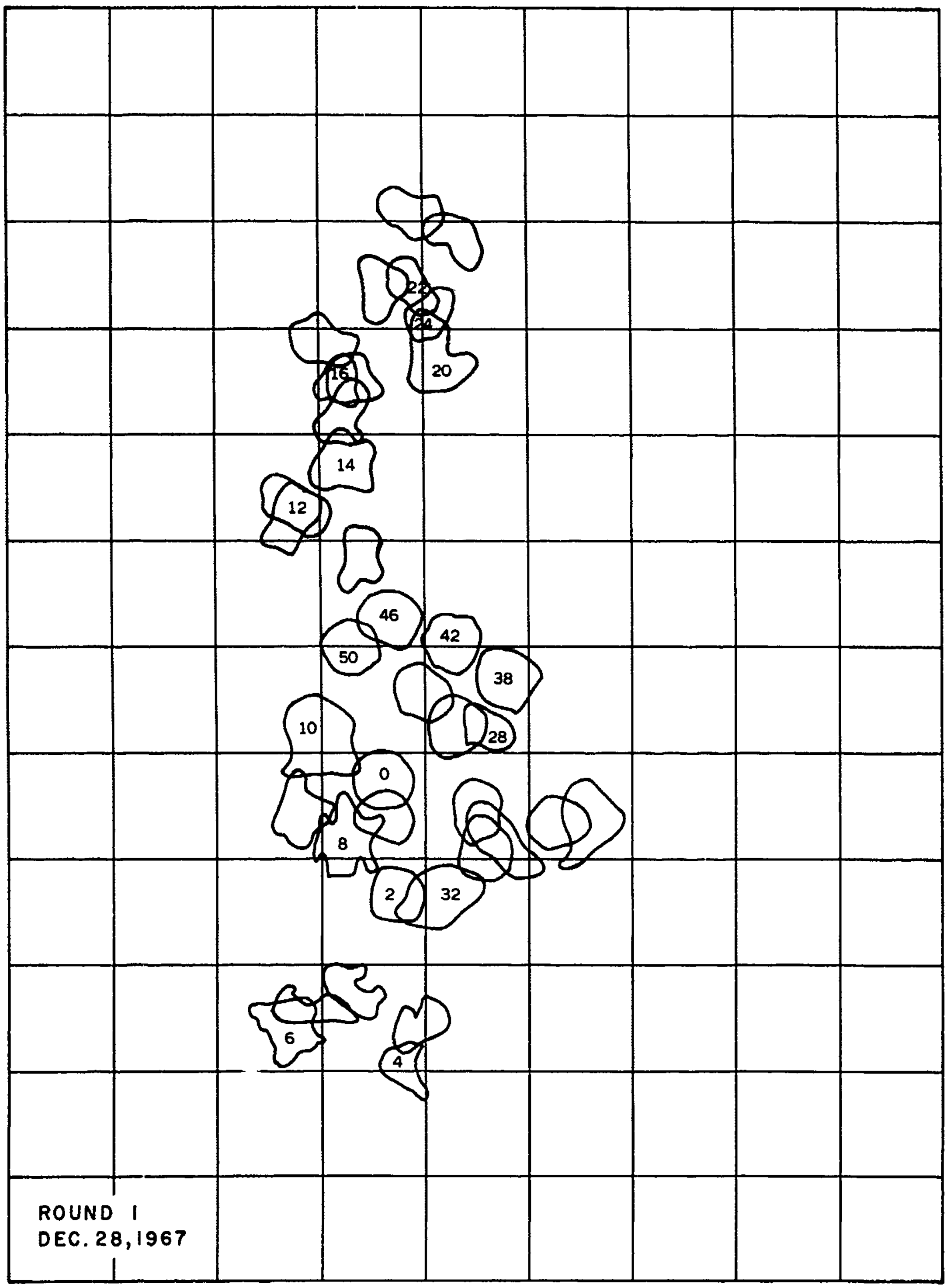


FIG. 8. Angular Displacement of the Discharge of the M-16 Rifle. Horizontal scale, .833 mrad/div; vertical scale, .416 mrad/div.

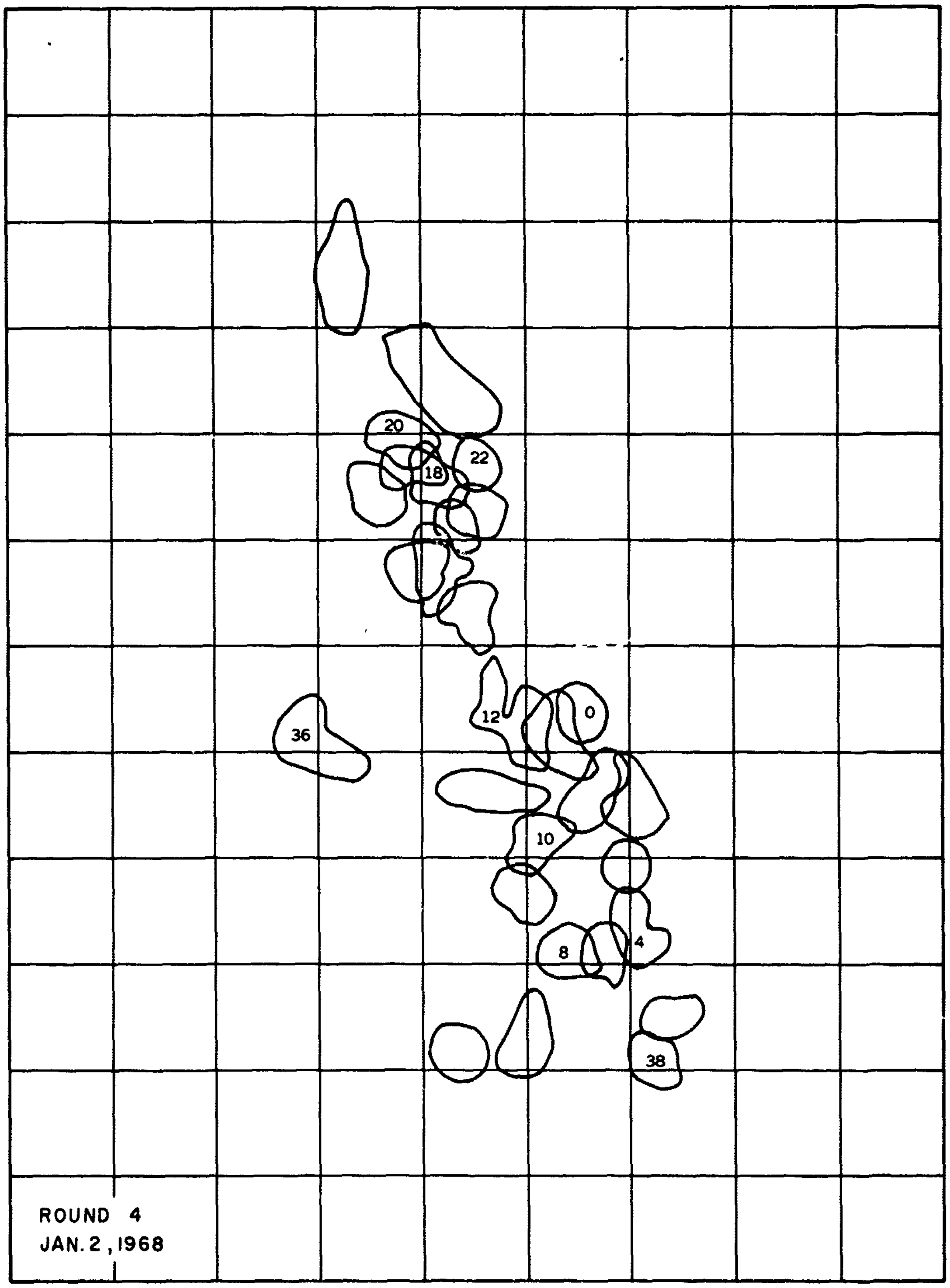


FIG. 9. Angular Displacement of the Discharge of the M-16 Rifle. Horizontal scale, .833 mrad/div; vertical scale, .416 mrad/div.

between mirror rotation and reflected beam angular displacement was 1:1. Rotation of the mirror in roll resulted in a 1:1 angular displacement of the beam in elevation. Experimental analysis showed that displacement contributions from roll were negligible.

The gross effect of weapon recoil is illustrated in Fig. 10 and 11. These pictures are 250-millisecond time exposures of the He:Ne light path traced on the target upon rifle discharge. The previously described experimental procedure was used; however, a Graflex camera was substituted for the high-speed Fastax camera. Upon detonation, the resulting motion of the rifle traced the recorded light path on the target.

In all the tests conducted on rifle recoil, the weapon was positioned in a "V" rest and held as naturally as possible. The "rest" was used as an alignment device; the rifleman exercised primary control over the weapon (Fig. 12). Recoil tests were conducted using blank ammunition.

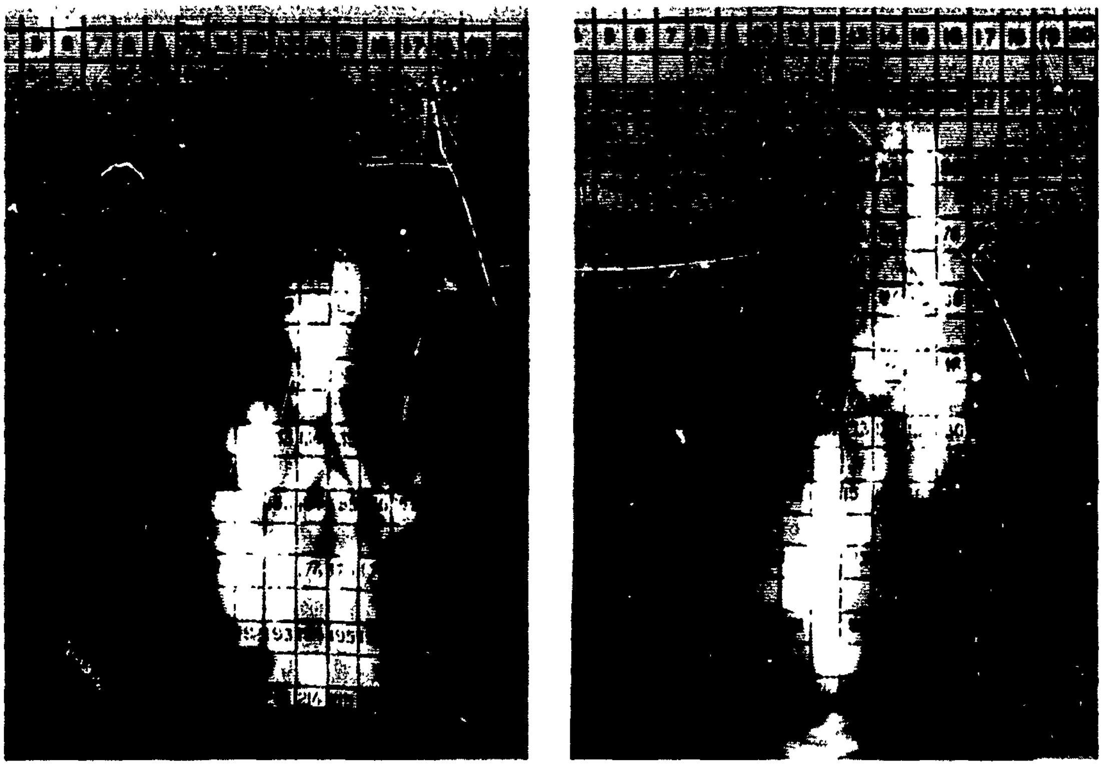


FIG. 10. 250-ms Time Exposures of M-1 Rifle Recoil Using Blank Ammunition. Horizontal scale, 1.042 mrad/div; vertical scale, 0.521 mrad/div.

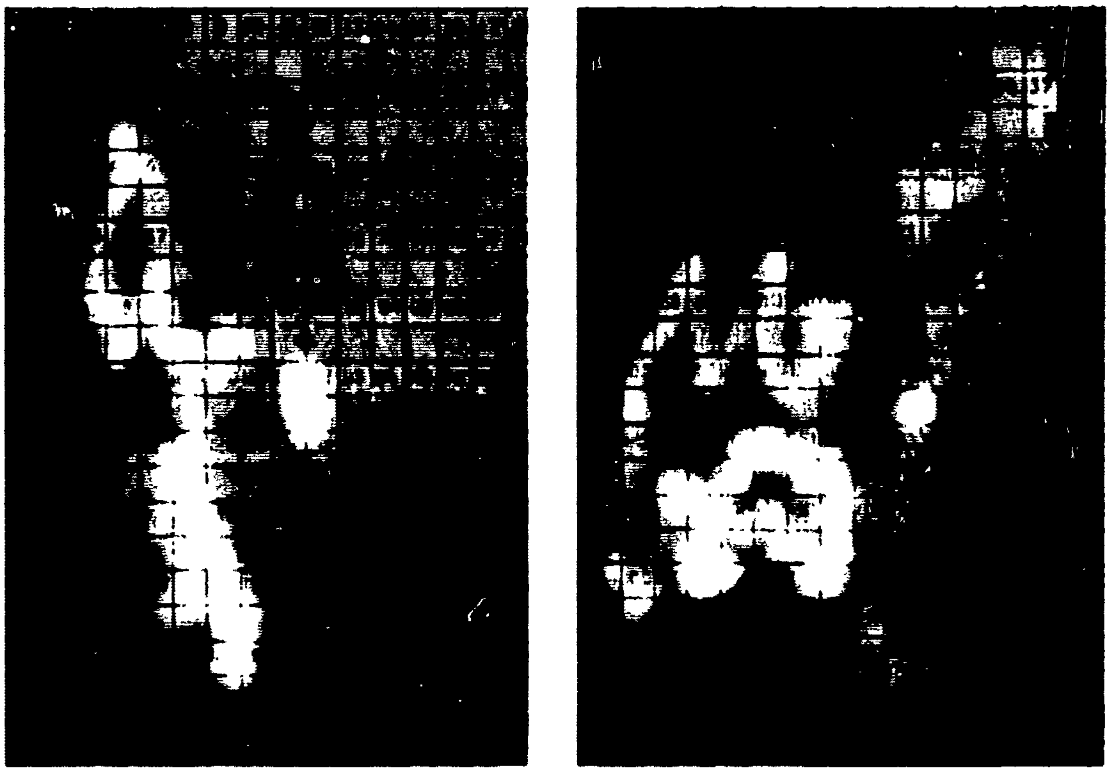


FIG. 11. 250-ms Time Exposures of M-16 Rifle Recoil Using Blank Ammunition. Horizontal scale, 0.833 mrad/div; vertical scale, 0.416 mrad/div.

FIG. 12. M-1 Rifle Positioned in "V" Rest.

ANALYSIS

The findings presented in the preceding section on rifle recoil presented a serious problem when applied to the DFSS concept. Consequently, a detailed investigation of the data gathered was required. The horizontal, x, and vertical, y, components of the laser beam displacement on the target versus time were plotted. Figure 13 is a typical plot of the displacement versus time for the x and y components of rifle recoil and is indicative of the magnitude of deflections encountered during each firing. Figure 14 is a typical plot of the instantaneous velocity components, v_x and v_y, versus time and reveals the rapidity with which the rifle moves after discharge and the "jerky" movements of the rifleman after firing.

These one-dimensional graphs do not completely define the seriousness of the recoil problem because the weapon did not move in this fashion. The weapon moved along a z or resultant component axis defined as the positive square root of the sum of the squares of the horizontal and vertical components,

$$z = \left|\sqrt{x^2 + y^2}\right|$$

Similarly, resultant velocity is defined as

$$v_z = \left|\sqrt{v_x^2 \quad v_y^2}\right|$$

Plots of the resultant components were prepared and examined to determine whether a period of time occurred, subsequent to rifle discharge, in which the muzzle direction was within a certain deflection angle from the original line of sight. If a recurring pattern of this nature occurred, a coded message could be delayed for transmission at the appropriate time. It would be imperative that such a pattern repeat with high probability from shot to shot.

Since a detection requires an optical hit, a maximum deflection angle in which a detection could occur must be established. A 2-foot-diameter beam on a target at a range of 100 yards indicates a maximum tolerable deflection angle of ±3 milliradians. Thus, the center line of the transmitted beam must be found within ±3 milliradians of the original sighting position at some time after rifle discharge and must remain within these limits for a period of time (undefined) to allow message transmission. This would define a "quiet zone" that must occur within a realistic period of time after discharge. The films were examined to determine this time lapse and it was concluded that after 20 milliseconds the rifleman's line of sight was so drastically changed that transmission must necessarily be keyed between 0 and 20 milliseconds after discharge. Displacement and velocity curves were plotted for this time interval to determine if a ±3-milliradian quiet zone existed. Figures 15 and 16

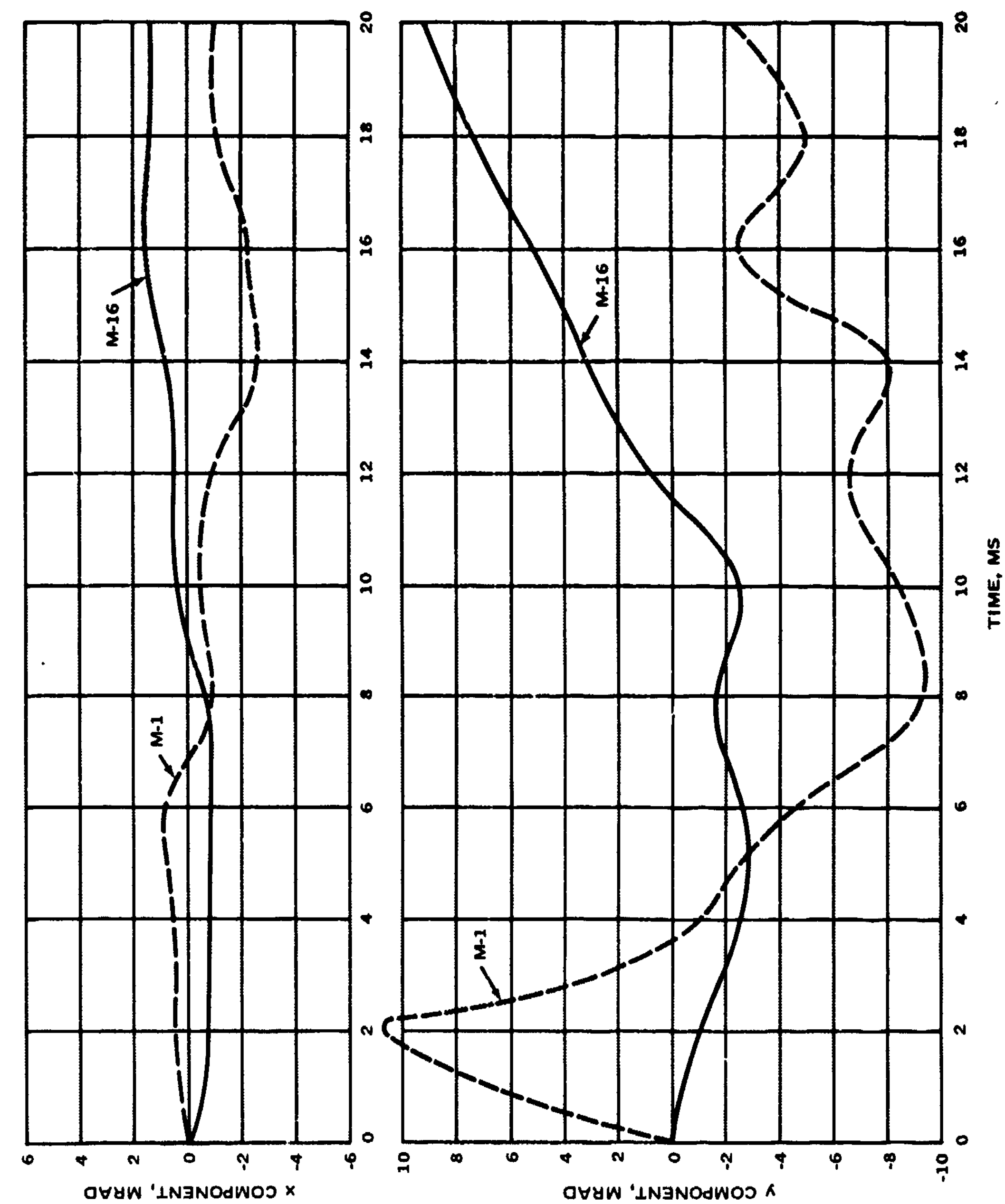


FIG. 13. Typical Displacement Versus Time, Horizontal (x) and Vertical (y) Components, M-1 and M-16 Rifles.

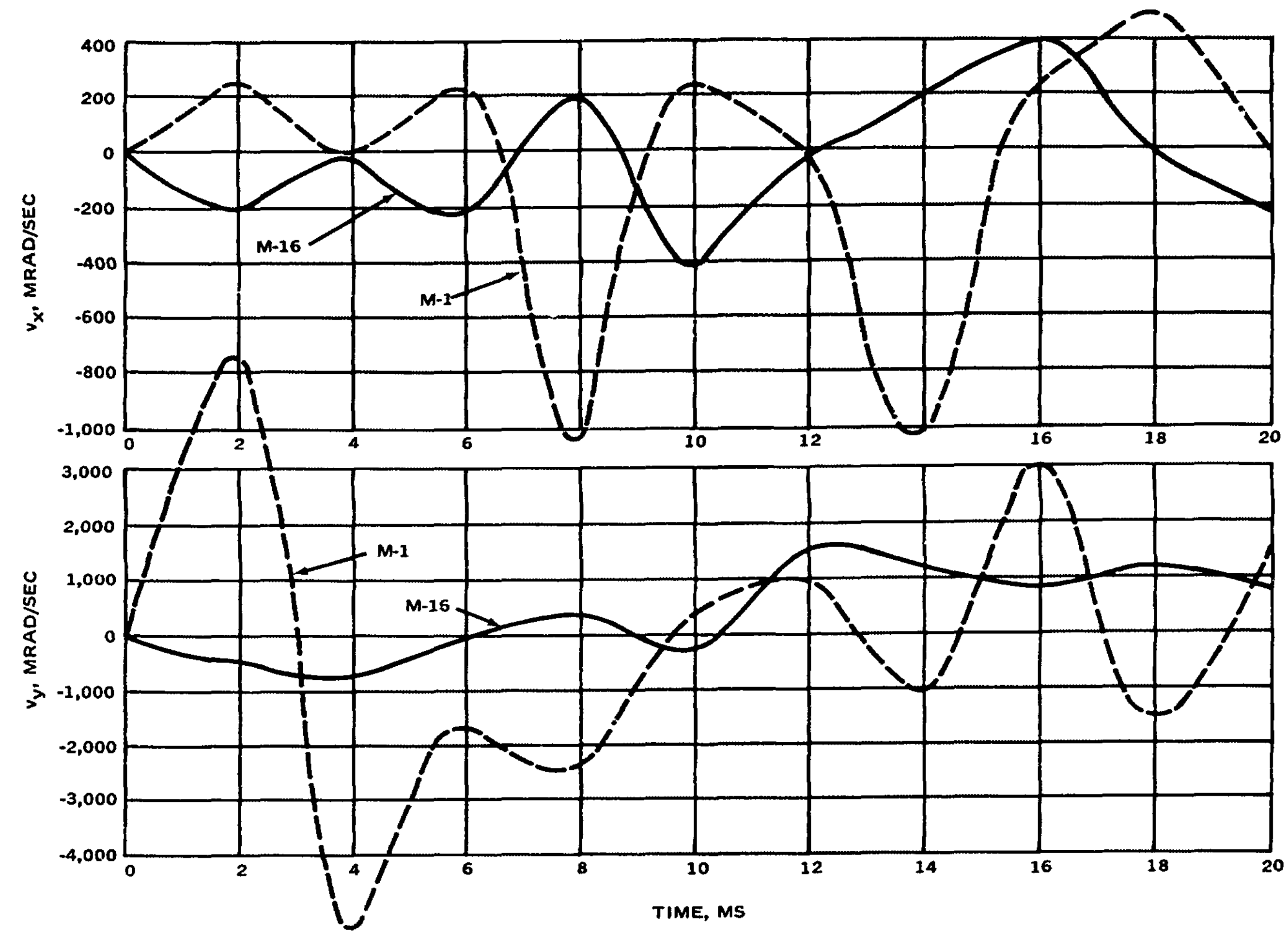


FIG. 14. Typical Instantaneous Velocity Versus Time, Horizontal (v_x) and Vertical (v_y) Components, M-1 and M-16 Rifles.

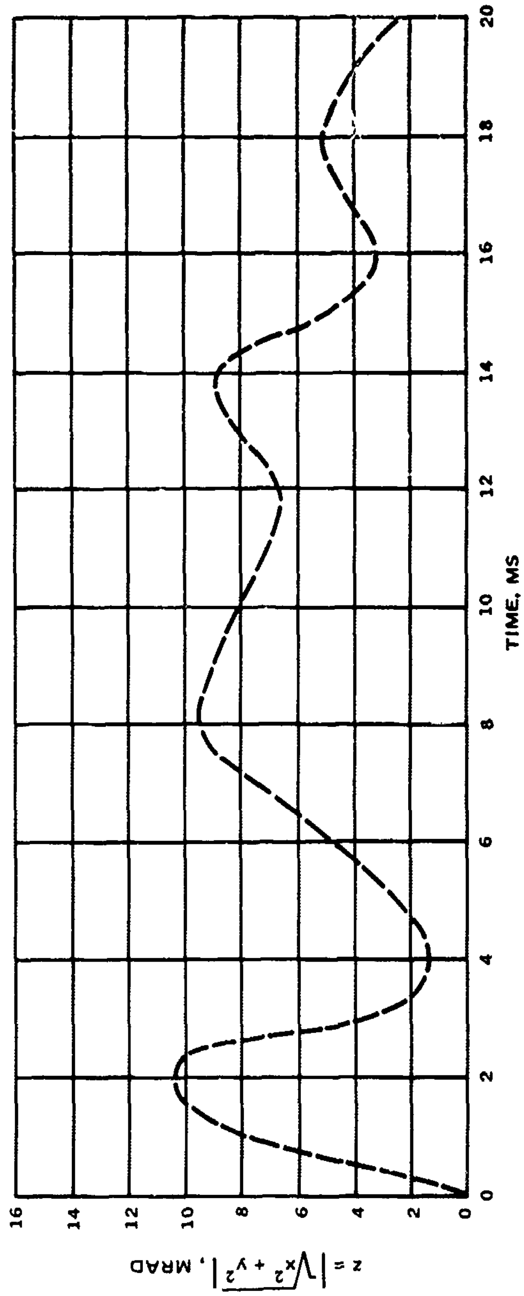


FIG. 15. Typical Resultant Displacement (z) Versus Time for the M-1 Rifle.

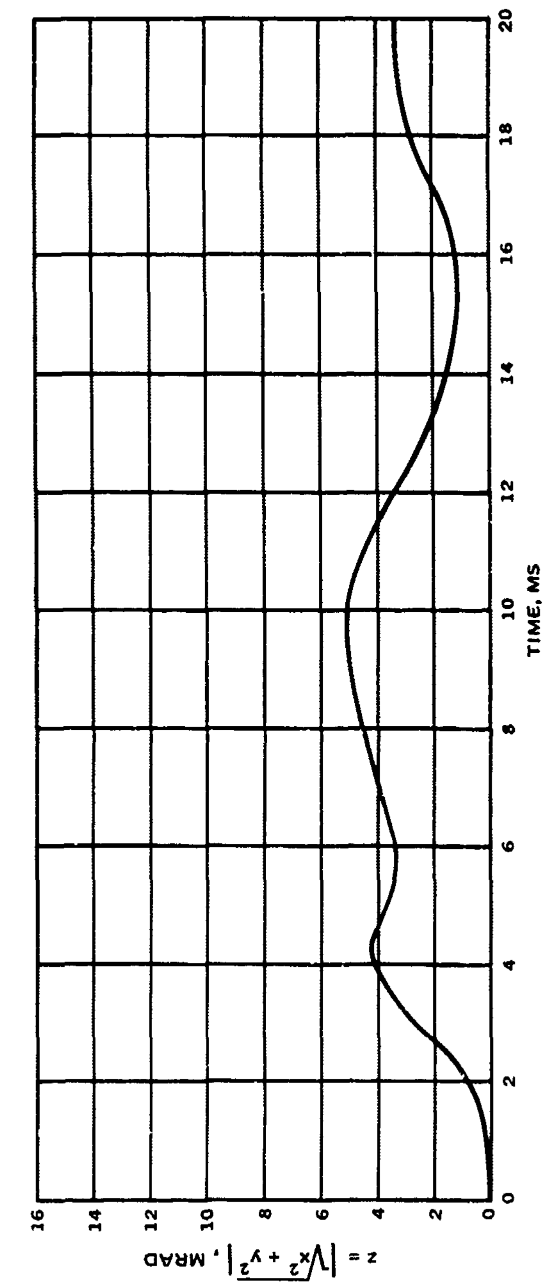


FIG. 16. Typical Resultant Displacement (z) Versus Time for the M-16 Rifle.

are typical plots of the resultant displacement versus time and it can be seen from the plots that the quiet zone does not appear. The oscillatory pattern of the curves indicates that the rifleman has little, if any, control over the recoil mechanisms. Figures 17 and 18 are typical curves of the instantaneous velocity versus time and show the significantly large velocities of oscillation of the rifle after discharge. These and all similar plots did not reveal the requisite quiet zone.

To summarize the data, a set of "extrema" curves for resultant displacement were prepared (Fig. 19 and 20) for all data recorded. When plotted on the same coordinate system, a maxima and a minima curve defines an envelope within which all curves for that weapon should fall. Off-scale values were omitted in the extrema plots because they indicate additional excursion error not measurable in the experiment. An open-bar histogram appearing below each envelope indicates the percentage of the total number of data points included within the envelope and thus the repeatability of the experiment. A shaded histogram, an index of the total number of data points recorded within the ±3-milliradian criterion at that point in time, is also shown. The shaded histogram is an experimental indication of the probability of a successful message reception.

ACOUSTICAL/MECHANICAL CONSIDERATIONS

The preceding investigations presumed that the DFSS signal transmission would be initiated by a "round counter," or other device, actuated by the firing of a blank round of ammunition. The study indicates that rifle recoil prohibits transmitting the message after or during the detonation of the round. Consequently, an investigation was made of the timing relationships of events internal to the weapon. To determine the available time intervals in which it would be possible to trigger and transmit an identification message without interference from recoil and muzzle shock, an M-16 rifle was instrumented and investigations were made to determine its various internal effects on message transmission and their timing relationship. Both automatic and semiautomatic firing, using blank ammunition, were investigated.

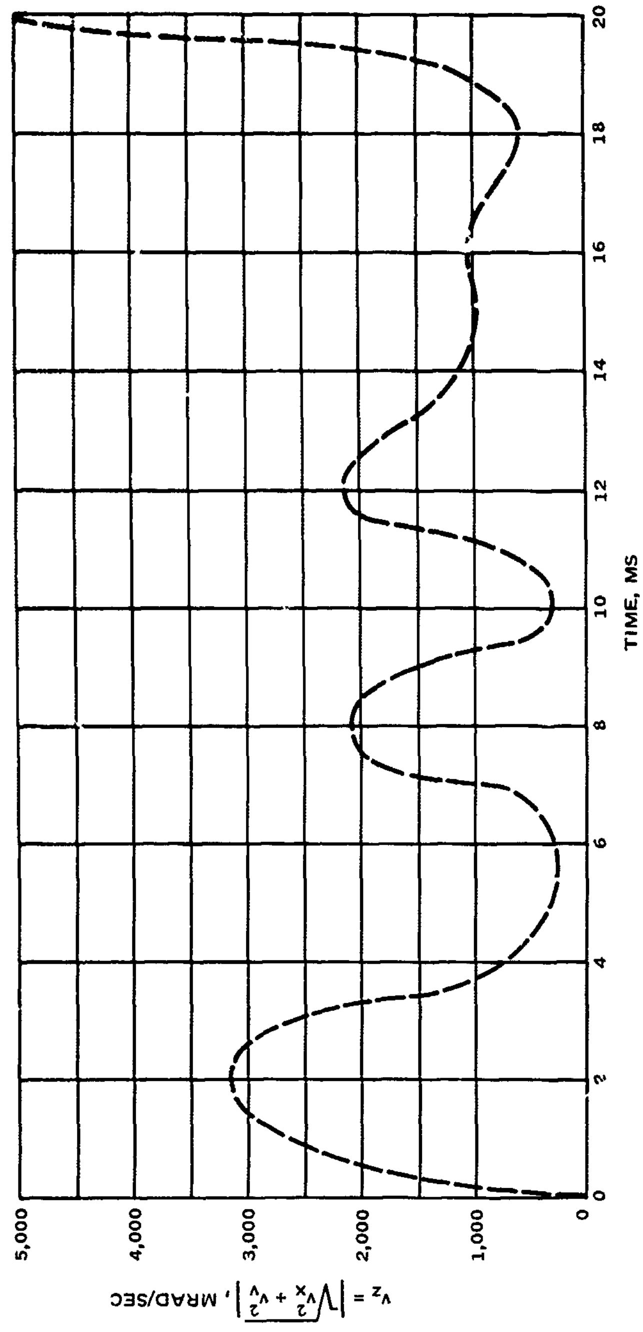


FIG. 17. Typical Resultant Instantaneous Velocity (v_z) Versus Time for the M-1 Rifle.

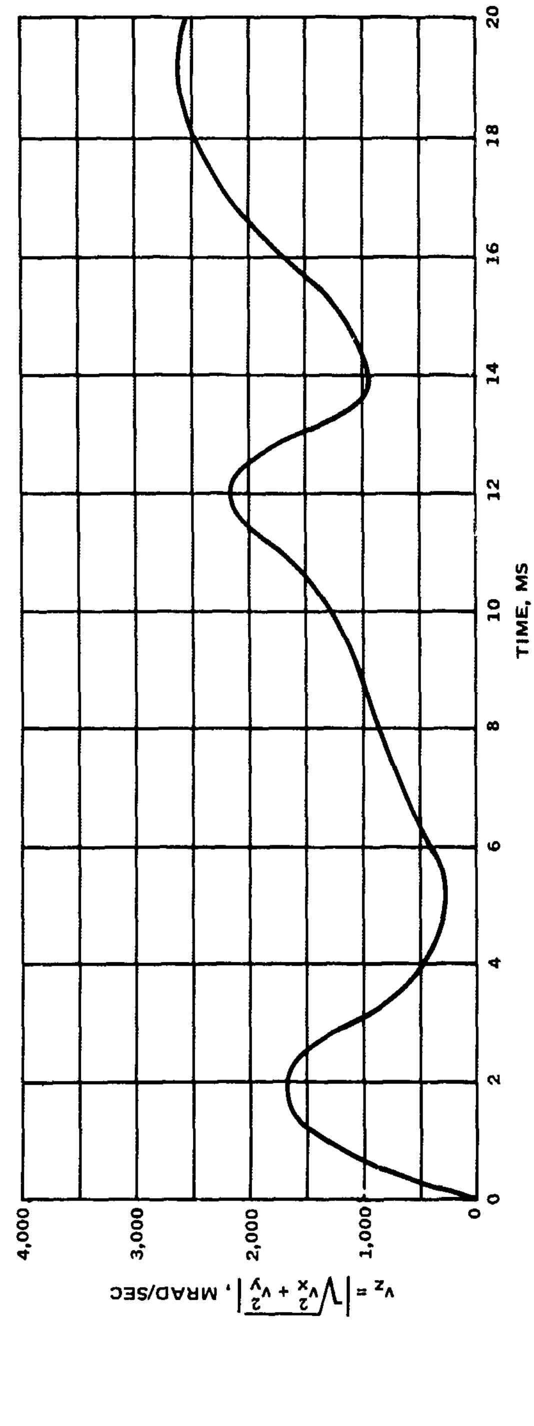


FIG. 18. Typical Resultant Instantaneous Velocity (v_z) Versus Time for the M-16 Rifle.

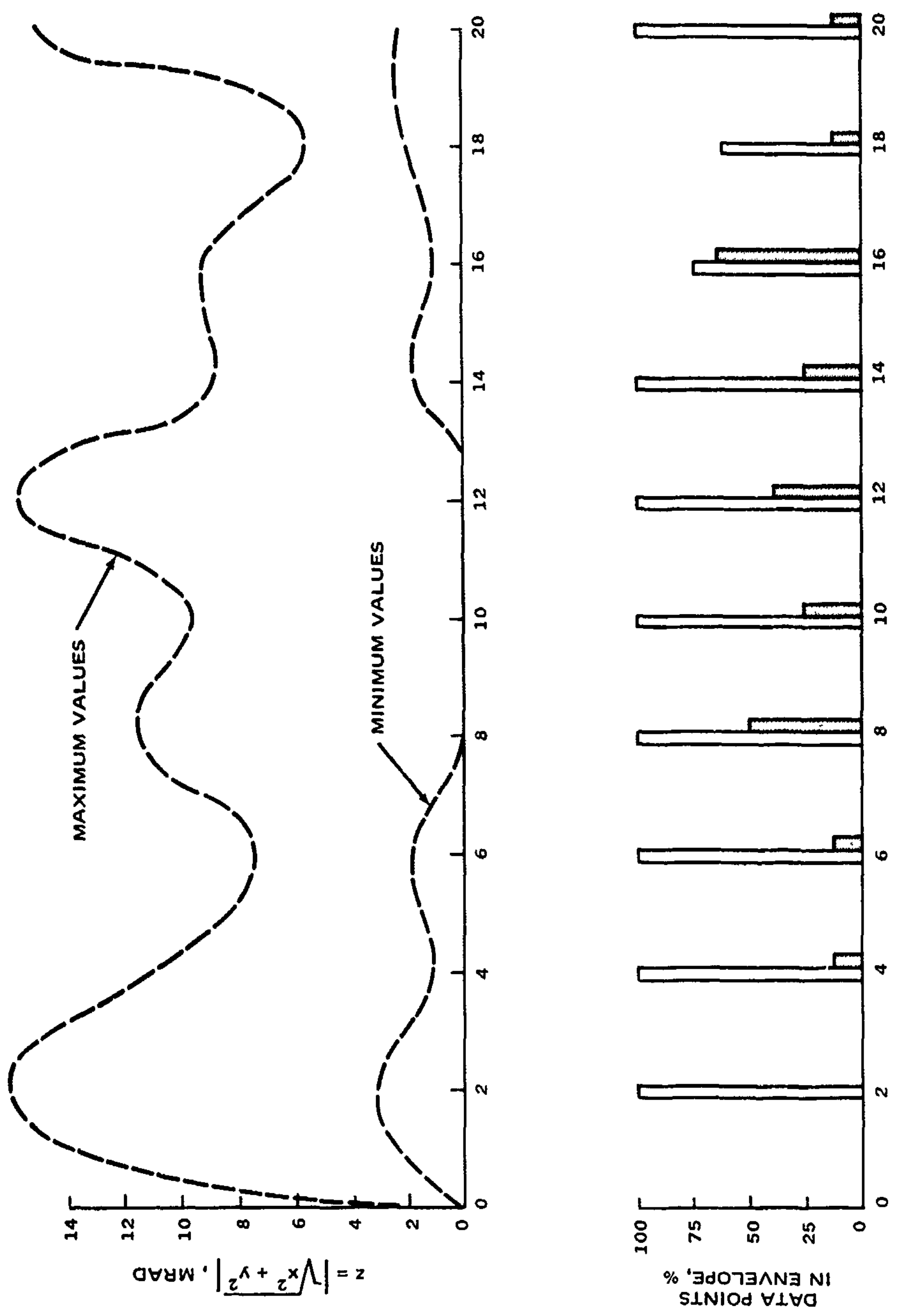


FIG. 19. Resultant Displacement (z) Extrema, M-1 Rifle.

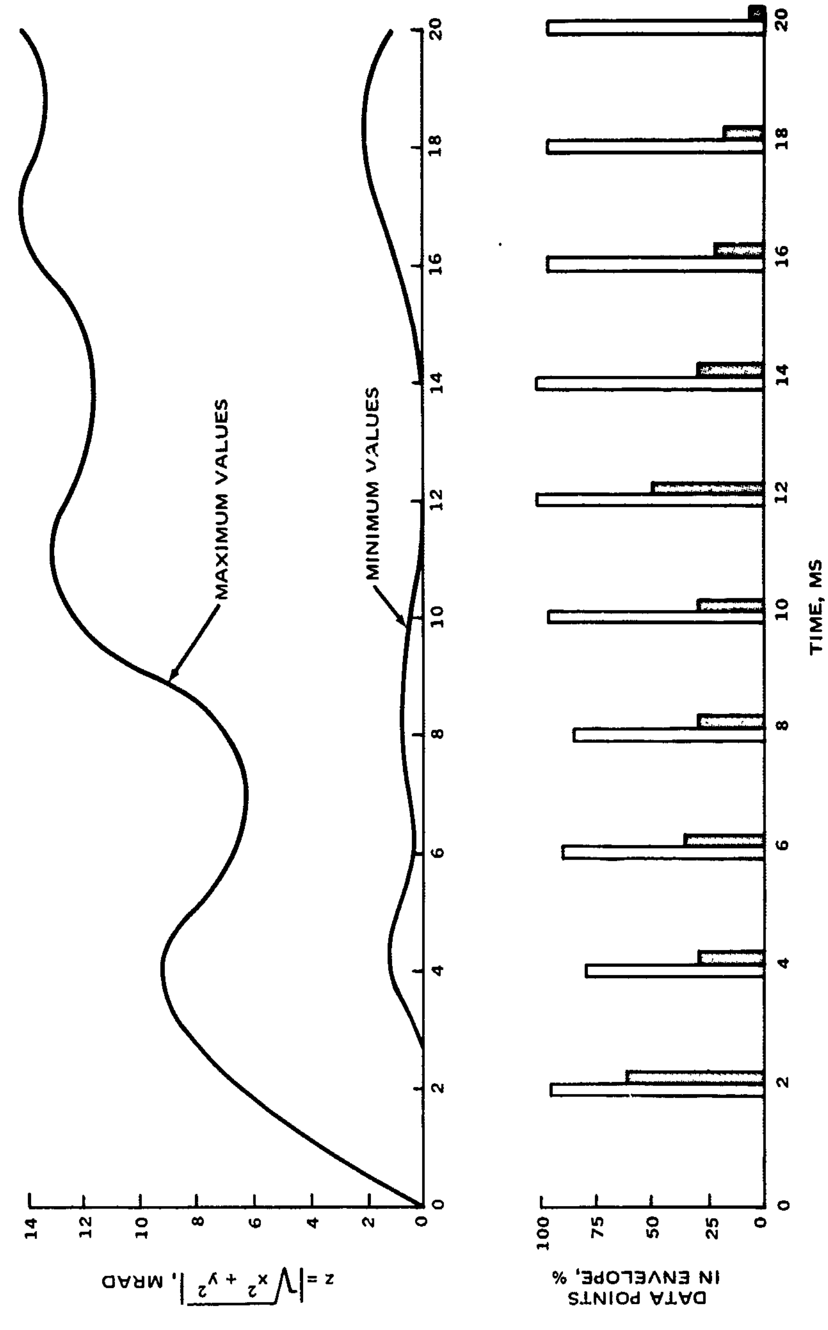


FIG. 20. Resultant Displacement (z) Extrema, M-16 Rifle.

The instrumentation consisted of a small crystal microphone attached to the magazine receptacle, a detector to observe muzzle flash, and a second detector to provide an indication of rifle recoil. The recoil measurement was intended to indicate the time that the muzzle was first observed to move during the firing of a blank round. To measure this time, a mirror was mounted on the bayonet stub of the weapon and a C-W He:Ne laser beam was reflected from it to a silicon detector. The rifle was hand-held in an alignment fixture. A motion of the muzzle of ±1 milliradian removed the signal from the silicon detector. Muzzle flash occurrence time was indicated by a silicon detector that was set to observe a large volume of space in front of the muzzle. It was presumed that the crystal microphone mounted near the breech of the weapon would detect the noise generated by the various physical occurrences inside the rifle with an insignificant time delay. A microswitch was actuated by the trigger a short time before hammer release to provide a signal for electronic triggering. Wide-band electronics (20 hertz to 20 kilohertz) were used throughout. All signals were recorded on an FM tape recorder and subsequently replayed on an oscilloscope. Timing was ultimately derived from the oscilloscope time-base generator. Timing error introduced by the tape recorder was less than 5%.

The photographed oscilloscope "trace results" of the firing of a round of blank ammunition is presented in Fig. 21. The upper trace of each picture represents the action of the trigger switch; the lower trace in each picture is, respectively, the noise detected by the microphone, the movement of the muzzle, and the occurrence of muzzle flash. If the time base of these pictures is expanded, a more significant comparison may be made of the timing relationship of the various events. Figure 22 compares the acoustic noise, recoil and muzzle flash detectors on an expanded scale of 5 milliseconds/division. Of particular interest are the times between (1) hammer release and hammer impact on the firing pin, (2) impact and recoil, and (3) impact and muzzle flash. The first interval averaged 8.0 milliseconds over a number of firings, the second interval was quite short (approximately 200 microseconds), and the third interval averaged 500 microseconds. One weapon was used for this investigation and although the measured effects were consistent for all rounds fired, minor variations would be expected from rifle to rifle.

To further understand the data, the action of the hammer was observed in a direct manner with the M-16 rigidly clamped to a bench. A He:Ne laser and a silicon detector were set on opposite sides of the rifle to allow radiation to pass through the thin slit left between the trigger housing group and the barrel/receiver group when the weapon was closed. The laser and the detector were positioned longitudinally, allowing the hammer to intercept the beam as it impacted the firing pin. The microphone was used to detect internal noises. The rifle was dry-fired several times and data were recorded. Figure 23 presents a typical oscilloscope trace of the signal from the silicon detector and

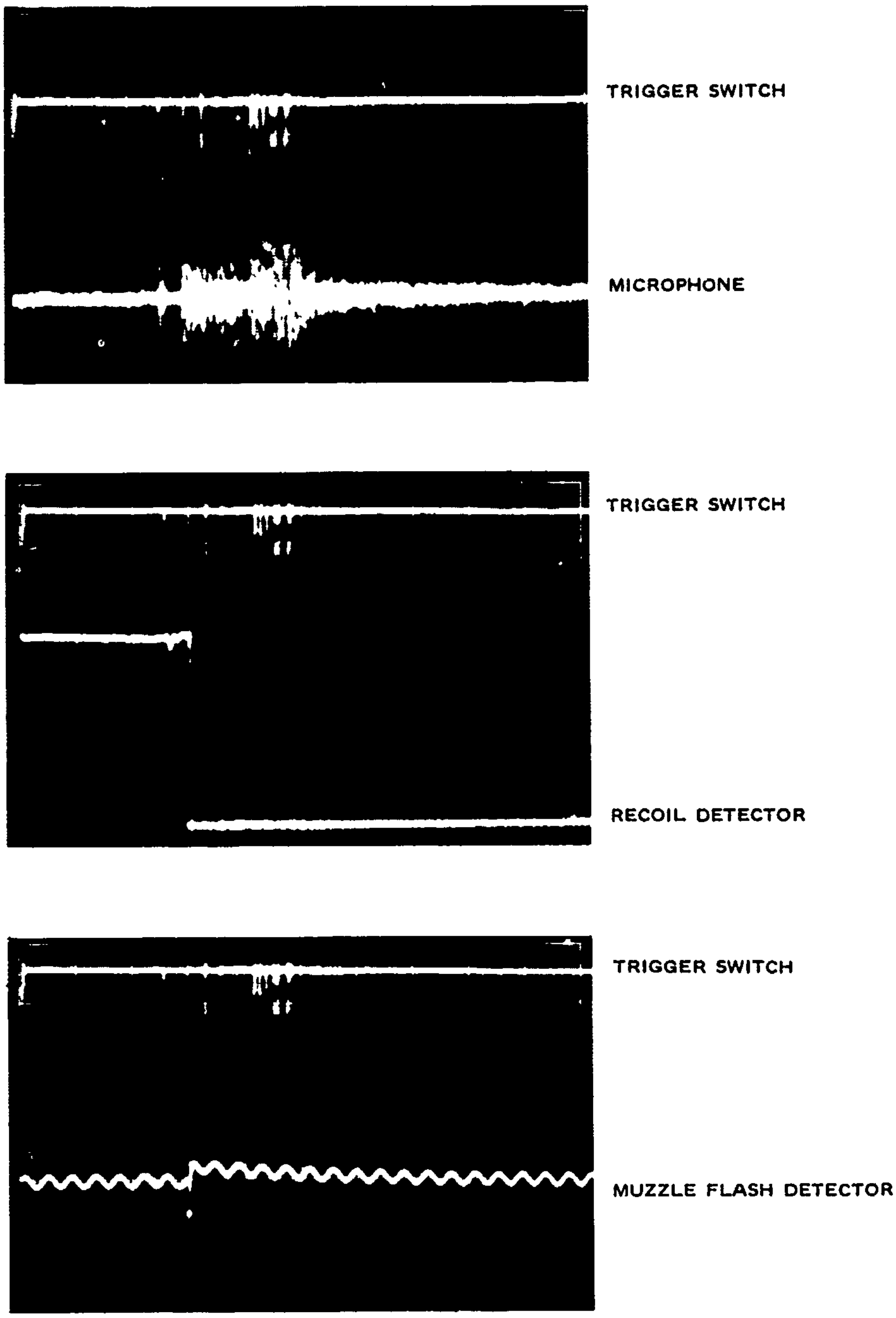


FIG. 21. Oscilloscope Photographs of M-16 Blank Round Firing Effects Upon Instrumentation. Horizontal scale, 20 ms/div.

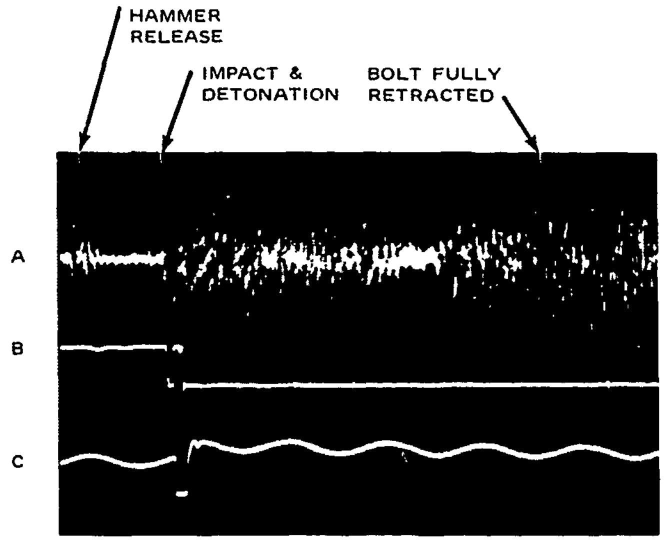


FIG. 22. Acoustic, Recoil, and Muzzle Flash Instrumentation Responses Compared in Time. Horizontal scale, 5 ms/div.

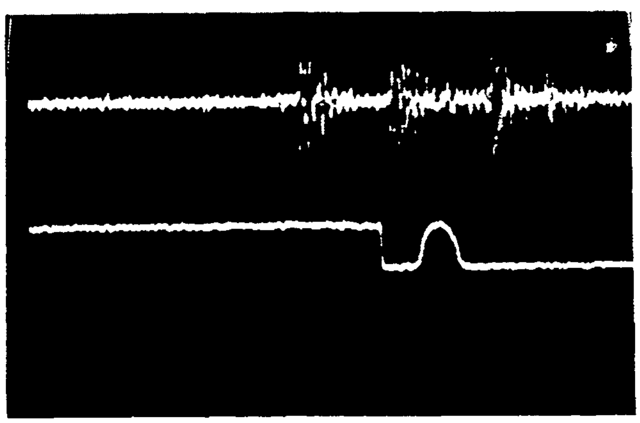


FIG. 23. Acoustic Noise Compared With Hammer Action. Laser and detector positioned near bolt. Horizontal scale, 5 ms/div.

the microphone. Of significance is the indication that the hammer impacts the firing pin 8 milliseconds after the first noticeable acoustic signal. To confirm suspicions about the origin of the first noise pulse, the laser and the detector were moved aft to a point where the hammer would interrupt the beam just as it was released from the sear. Figure 24 shows that the first acoustic signal and the laser beam interruption occur simultaneously.

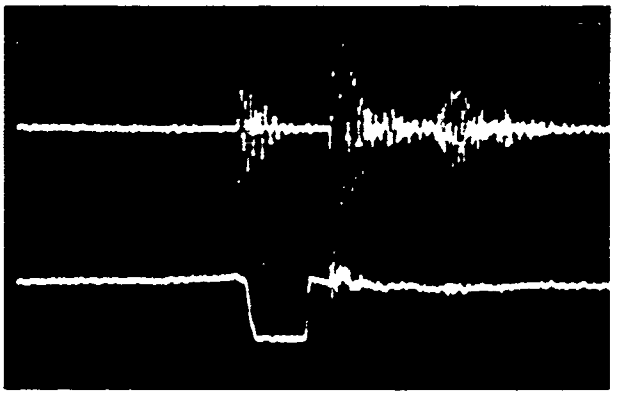


FIG. 24. Acoustic Noise Compared With Hammer Action. Laser and detector positioned away from bolt. Horizontal scale, 5 ms/div.

The foregoing demonstrated that an M-16 rifle presents an inherent effect of sufficient magnitude, and sufficiently before other disturbances, to trigger the signals required from the DFSS transmitter when the weapon is operated in the semiautomatic mode. Unfortunately, this effect does not present itself before each shot when the M-16 is operated in the automatic mode.

To determine if there might be some identifiable effect sufficient for transmitter triggering purposes when the weapon was operated in the automatic mode, the latter experiment mentioned was repeated using blank ammunition in four-round bursts; the muzzle flash signal was included. Figure 25 presents the resulting signals with a sweep time of 10 milliseconds/division. Events are noted that were deduced from inspection of the actuating mechanisms. To also meet the constraints of other system requirements, it would appear that acoustic means of obtaining a triggering signal is not possible. The action of the hammer, however, presents a clue as to how such a signal, at a proper time, might be obtained. The insertion of a microswitch or piezoelectric crystal, actuated by hammer release, could provide up to 8 milliseconds of transmission time before cartridge detonation and the subsequent rifle recoil.

CONCLUSIONS

This study has demonstrated that muzzle blast from shoulder-type weapons does not irreparably disrupt communication signals from a DFSS device. However, the effect of rifle recoil presents a serious problem,

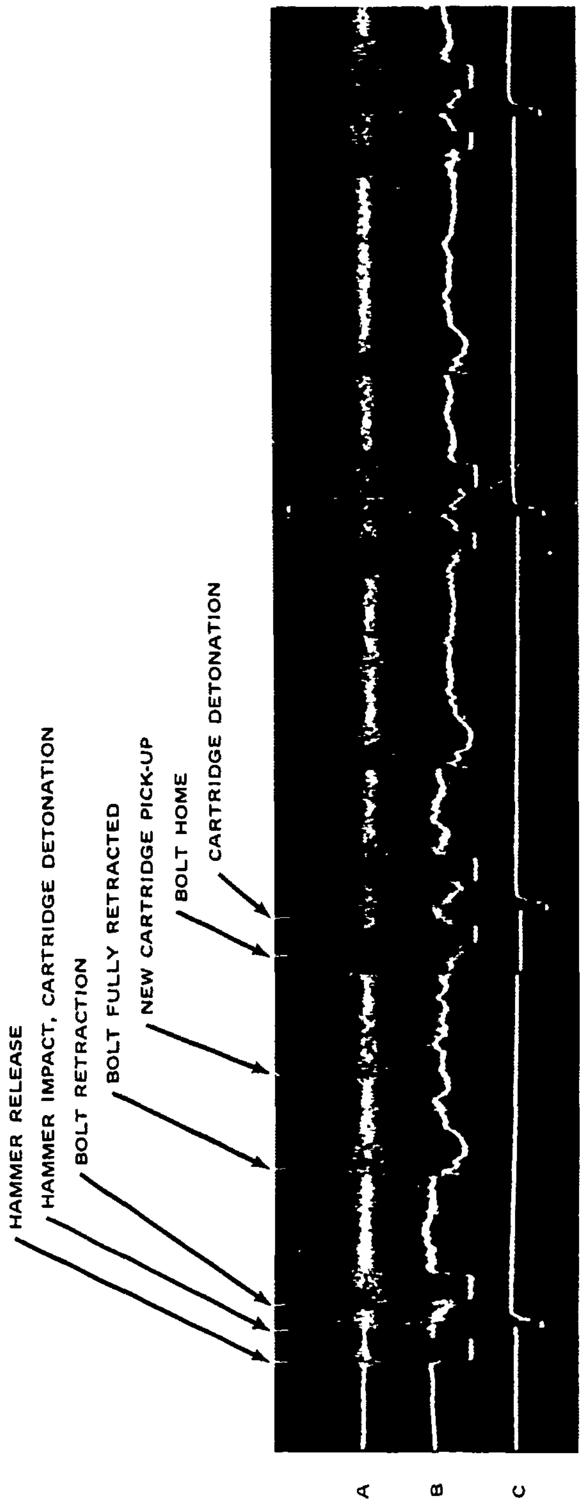


FIG. 25. Acoustic (A), Hammer Action (B), and Muzzle Flash (C) Detectors Compared During Automatic Fire. Horizontal scale, 10 ms/div.

as defined by the graphs of line-of-sight displacement, velocity, and resultant position components. These curves indicate a significant inverse relationship between rifle recoil and the probability of message detection. Analysis failed to reveal a quiet zone and the curves of extrema substantiated this fact by indicating a high degree of uncertainty in the line of sight of the rifle after discharge. Any set of data may be considered as typical since there was little repeatability from shot to shot. In addition, transmission time studies, as related to various mechanical functions of an M-16 rifle, were investigated. These investigations indicate that modification of the weapon to include a piezoelectric crystal or microswitch, to be triggered by the hammer release, could provide the necessary time required for message transmission.

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13 ABSTRACT

This report presents the results of experiments conducted to determine the origin, magnitude, and characteristics of signal interference in the Direct Fire Simulation System (DFSS) communications caused by weapon recoil and shock wave effects. The two effects were considered independently and were investigated using an M-1 (.30 caliber) and an M-16 (.233 caliber) rifle. Of primary concern in this investigation were the effects of blank ammunition although a limited amount of data was gathered on ball ammunition. Transmission time intervals required for sending and receiving a coded message, as related to various mechanical aspects of the rifles, were also investigated.

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